AIR FORMED ARCH CULVERT CONSTRUCTION
Crawford County

Construction Report
Highway Research Advisory Board
Project HR-314

May, 1991

Highway Division
Iowa Department of Transportation

CONSTRUCTION REPORT
HIGHWAY RESEARCH ADVISORY BOARD
PROJECT HR-314

AIR FORMED ARCH CULVERT CONSTRUCTION
CRAWFORD COUNTY

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TABLE OF CONTENTS

	PAGE
ACKNOWLEDGEMENTS	1
ABSTRACT	2
INTRODUCTION	3
PROBLEM STATEMENT	4
OBJECTIVE	5
PROJECT DESCRIPTION	5
CONSTRUCTION	7
Pre Culvert Work	7
Culvert Floor and Curtain Walls	7
Mix Design	8
Arch Construction	10
POST CONSTRUCTION OBSERVATIONS	12
CONCLUSIONS	13
APPENDICES	
A. Contract	14
B. Material Sources	16
C. Aggregate and Sand Gradations	18
D. Mix Design	21
E. Concrete/Shotcrete Testing	23
F. Construction Photographs	27

DISCLAIMER

METRIC CONVERSION

1 INCH = 2.54 CENTIMETERS (cm)

1 FOOT = 0.3048 METERS (m)

1 CUBIC FOOT = 0.028 3168 CUBIC METERS (m^3)

1 CUBIC YARD = 0.764 555 CUBIC METERS (m^3)

1 MILE = 1.609 34 KILOMETERS (km)

1 POUND (MASS) = 0.453 592 KILOGRAMS (kg)

1 POUND (FORCE) = 4.448 218 NEWTONS (N)

1 PSI = 6.894 733 KN/m^2 (kPa)

1 GALLON = 0.003 785 CUBIC METERS (m^3)

1 SQ. YARD = 0.836 127 SQ. METERS (m^2)

1 POUND/CUBIC FOOT = 16.018 477 KILOGRAMS/CUBIC METERS (kg/m^3)

1 ACRE = 0.404 686 HECTARES (ha)

ACKNOWLEDGEMENTS

This research project was sponsored by Crawford County and the Iowa Department of Transportation through the Highway Research Advisory Board. Partial funding for this project was from the Secondary Road Research Fund in the amount of $16,500.

The authors wish to extend appreciation to the Crawford County Board of Supervisors and the Iowa DOT for their support in developing and conducting this project. The Crawford County and Iowa DOT District 3 inspection personnel, Capital Construction Company, Inc. of Logan, Iowa and Concepts in Concrete of Tulsa, Oklahoma also deserve recognition for the extra effort put forth on this project.

ABSTRACT

Iowa's secondary roads contain nearly 15,000 bridges which are less than 40 feet (12 m) in length. Many of these bridges were built several decades ago and need to be replaced. Box culvert construction has proven to be an adequate bridge replacement technique. Recently a new bridge replacement alternative, called the Air-O-Form method, has emerged which has several potential advantages over box culvert construction. This new technique uses inflated balloons as the interior form in the construction of an arch culvert.

The objective of research project HR-314 was to construct an air formed arch culvert to determine the applicability of the Air-O-Form technique as a county bridge replacement alternative.

Post construction inspection of the air formed arch culvert showed the Air-O-Form method can be used to construct a structurally sound arch culvert. However, this method must become more economical if it is to compete with box culvert construction for county and state culvert projects.

INTRODUCTION

Iowa's secondary road network contains nearly 15,000 bridges which are less than 40 feet (12 m) long. Many of these bridges were constructed several decades ago and are now becoming either structurally deficient or functionally obsolete.

One method often used to replace such a bridge is to construct a single or multiple box culvert. This type of construction has proved to be an adequate replacement for bridges. However, box culvert construction can be expensive and time consuming. Construction is slowed because forms cannot be removed and reused until the poured concrete reaches an acceptable strength.

Recently, a new method of culvert construction has been developed. The Air-O-Form technique, as it is known, uses an air inflated balloon as the inside form for the construction of an arch shaped culvert. The balloon can be inflated quickly, saving time the contractor would otherwise spend forming the box culvert. The balloon used can also be made to fit a variety of shapes and sizes.

The arch shape offers several advantages over a box. First, the arch is structurally more efficient than the box. A culvert of greater strength can be constructed using less steel and concrete. Also, the arch can be hydraulically more efficient. A third advantage is the absence of a wall in the center of the structure such as found in multiple box culverts. This eliminates an obstruction and allows debris to flow through the structure.

The Air-O-Form method of arch culvert construction involves the following six steps.

1. Placement of a reinforced bottom slab or footing.
2. Placement of flexible metal straps in the desired shape of the arch and inflation of the balloon form. (The straps hold the balloon form in the desired shape.)
3. Placement of longitudinal and vertical steel reinforcement around the inflated form.
4. Adjustment of the air pressure inside the form to the required pressure.
5. Application of 6 inches (15 cm) or more of shotcrete in one lift.
6. Deflation and removal of the balloon form once the shotcrete has gained the necessary strength.

PROBLEM STATEMENT

Many of the smaller bridges built on Iowa's secondary road system are several decades old.

Heavy loads from today's farm product transport equipment are stressing these bridges beyond their design strength. Therefore, these bridges must be replaced.

Funds for bridge replacement projects are taking up an ever increasing portion of the county budget. If an inexpensive alternative to box culvert construction can be developed, considerable savings can be realized. The Air-O-Form method of arch culvert construction has the potential to be such an alternative.

OBJECTIVE

The objective of this research project was to construct an air formed arch culvert to determine its applicability as an alternative county bridge replacement technique. Specific topics to be researched include:

1. The cost and time savings which can be realized using the air form technique.
2. The strength and durability properties of the shotcrete used in the structure.
3. The long term structural capacity of the arch.

PROJECT DESCRIPTION

The location selected (Figure 1) for installation of the air formed arch culvert was the easternmost of two bridges located on a granular surfaced road separating sections twelve and thirteen in Nishnabotna Township (12 & 13-82N-38W). The bridge it replaced could no longer safely support the heavy loads of today's farm equipment. Also, during heavy rains, the creek occasionally rose above the bridge deck making travel hazardous.

The arch culvert was designed to drain a 950 acre (385 ha) area in southeastern Crawford County. Hydraulic calculations showed a culvert end area of 110 square feet (10.2 m²) was needed to carry the peak water flow from a 25-year flood. Based on this information, a semicircular arch having a 9 foot (2.7 m) radius and a culvert length of 52 feet (16 m) was needed to meet roadway width requirements.

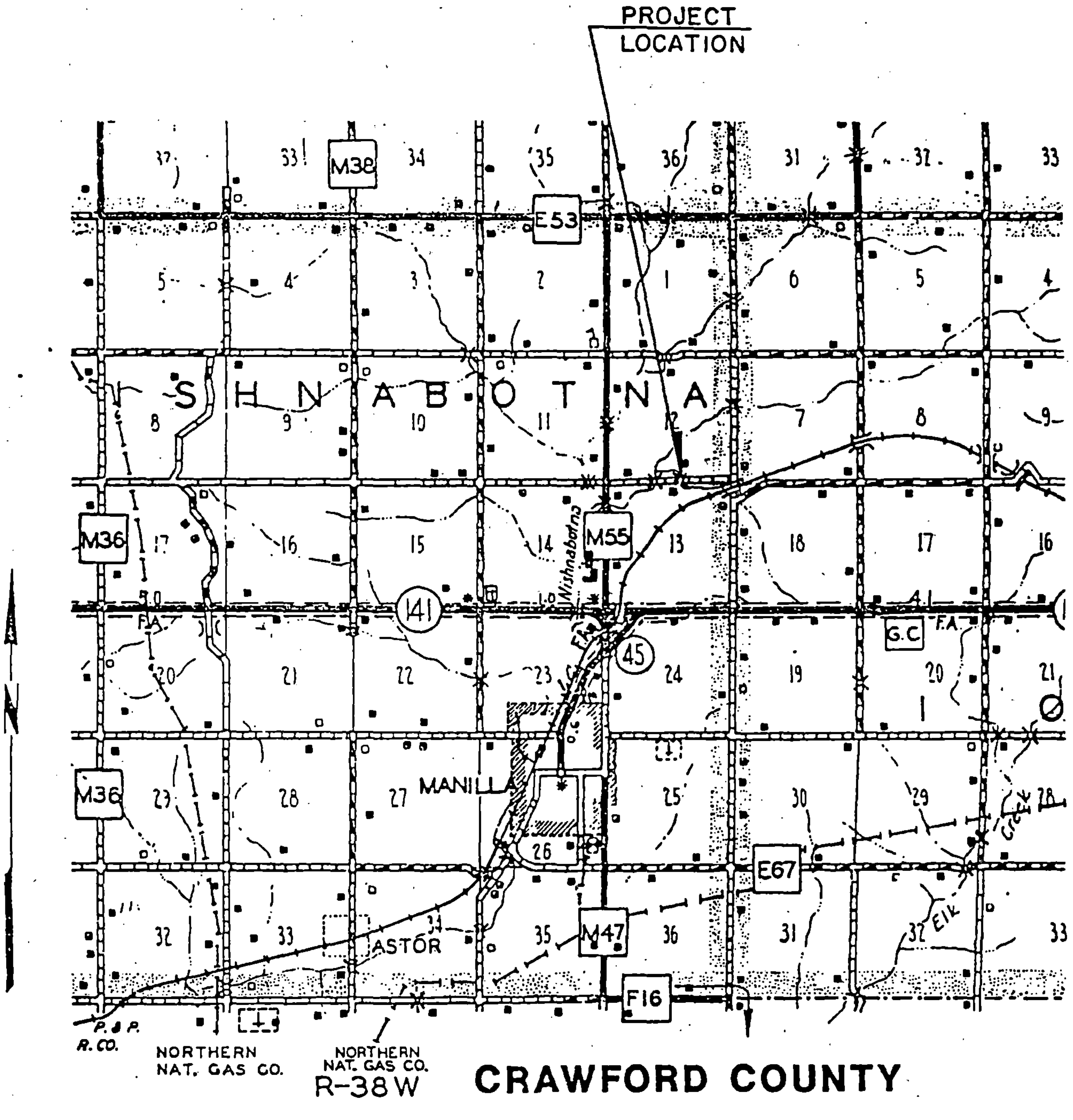

Figure 1 Project Location

CONSTRUCTION

Capital Construction Company, Inc. of Logan, Iowa was awarded the contract to construct the arch culvert. A copy of the contract is in Appendix A.

Pre Culvert Work

Before the contractor began constructing the culvert, bridge removal and excavating work were required. The contractor began to remove the existing 24 feet x 16 feet (7.3 m x 4.9 m) bridge and abutments on October 10, 1990 and all the excavation work was completed by October 16, 1990.

Culvert Floor and Curtain Walls

On October 22, 1990 the contractor began work constructing the arch culvert. Although the contractor had experience in other types of concrete work, this was the first experience the contractor had constructing a culvert by shotcrete, a pneumatically applied concrete mix. Forms for the inlet and outlet curtain walls were placed as well as the reinforcing steel for the pour made later in the day.

The following two days were spent placing the forms and reinforcing steel for the footing. With the steel in place on bar chairs and correctly spaced, the pour was made and later covered with wet burlap for proper curing.

Mix Design

The original mix design gradation submitted was compared to American Concrete Institute (A.C.I.) 506.2-77 Rev 83 Part 2 Table 2.2.1 gradation No. 2 and was found to be low on material passing the No. 50 sieve and No. 100 sieve. This was pointed out to the shotcrete subcontractor. 100 lbs. (45 kg) of fly ash was then added to improve the pumpability of the fine mix. According to the applicator, it is desirable to have 15-16% passing the No. 50 sieve and 4% passing the No. 100 sieve, or a minimum of 20% passing the No. 50 and No. 100 sieves combined. Materials sources are listed in Appendix B.

Due to the A.C.I. gradation demands and the availability of produced material that would provide the combined grading needed, mortar sand, concrete sand, and 1/2" (1.3 cm) coarse gravel were required in the mix. Hosteng Ready Mix Company, Denison, only had 2 bin capability for aggregate proportioning. The problem was solved by proportioning the mortar sand (60%) and concrete sand (40%) through the ready mix plant and blending them in a transit mixer. The pre-blended sand was then stockpiled for proportioning into the shotcrete mix along with the 1/2" (1.3 cm) gravel using 70% blended sand and 30% 1/2" (1.3 cm) gravel. The final gradations and mix design are given in Appendices C and D.

Samples of shotcrete were obtained at the transit mixer discharge chute prior to pumping and also from 30" x 30" (76 cm x 76 cm) shotcrete applied test panels that were 8 inches (20 cm) thick.

The samples were obtained from the shotcrete applied panels for the full depth of the application. All testing of the plastic concrete was then accomplished following Iowa Department of Transportation Instruction Memorandum (I.M.) testing procedures.

Comparisons were made between the air content of the shotcrete applied concrete and the air content of the shotcrete mix prior to pumping. The percent air loss due to application ranged from 1.2% to 1.5%. The same comparison was made for the slump change in the shotcrete. There was a range of 1 inch to 1 3/4 inch (2.5 cm to 4.4 cm) slump reduction in the applied shotcrete mix. Two test panels with reinforcing conforming to the design spacing were made up with shotcrete applied approximately 8 inches (20 cm) thick. The first panel was evaluated for reinforcing embedment immediately after shotcrete was applied. This was accomplished by carefully removing the plastic concrete and visually inspecting for dense concrete around the reinforcing. The second test panel was allowed to set overnight. Two cores were then cut from the panel. One core was through the reinforcing bars near their intersection and the second core was through a single reinforcing bar.

Visual examination showed very good embedment of the bars in both cores. Directly below the reinforcing bar intersection there appeared to be a reduction in coarse aggregate in the applied shotcrete. This was probably due to rebound loss of coarse aggregate striking the reinforcing during shotcrete application.

Arch Construction

Once the floor and curtain walls were completed, the contractor began work on the air formed arch.

The first step in this process was to bolt a perforated angle iron on each side of the floor at the location where the floor meets the arch. Metal straps were then cut to the desired length and attached to the angle irons through the perforations. The steel straps act to hold the inflated balloons in the desired arch shape. The contractor also widened and lengthened the excavated area to accommodate the 80 foot (24 m) long balloons.

After inflating both balloons, it was noticed that one had several holes, possibly caused by the reinforcing bars at the site, and the Air-O-Form subcontractor decided to use just one balloon for the arch shape. Consequently, the single balloon was expected to stretch 5% more than normal causing the sides of the balloon to roll away from the reinforcing cage. Plywood boards placed along the sides provided a surface to shotcrete against, somewhat compensating for this problem.

After inflating the balloon to the air pressure of 0.83 psi (5.7 kPa), the contractor began placing reinforcing steel. Number 4 bars were used for longitudinal steel reinforcement and were placed at 7.5 inch (19 cm) spacings. Number 5 bars were then used for transverse reinforcement and spaced 4.0 inches (10 cm) apart. The reinforcement was set away from the balloons by strings of steel chairs placed around the arch. The entire operation, from positioning the deflated balloons to finishing placing the reinforcing steel, took two days. Once the steel was in place the arch was ready to be shotcreted.

On Thursday, November 1, 1990 the arch culvert was shotcreted. Two crews consisting of a nozzleman and blow pipe operator worked on opposite sides of the arch in order to keep the weight of the shotcrete evenly distributed around the balloon. Shotcrete was applied full depth approximately 7.0 feet (2.1 m) high along the length of the culvert. A two hour set-up time was allowed for this first section and then the top of the culvert was completed by shotcreting from a mobile platform. The entire process took approximately eight hours.

Crawford County and Iowa DOT personnel were present and performed testing throughout the shotcreting operation. Test results are listed in Appendix E.

After the arch was completed, the contractor applied a white pigment curing compound by Dayton Superior and covered the arch with insulated blankets. The balloon was kept inflated while the arch developed enough strength to support itself. A determination was made by Crawford County to keep the balloon inflated until a shotcrete strength of 1700 psi (11,720 kPa) was reached as determined from cylinders made at the beginning of the shotcreting operation. This requirement was met in one day, and on November 2, 1990 the balloon was deflated and removed.

Work on excavation for the east culvert headwalls began on November 5, 1990. It was slow going as a result of light rain, snow and muddy conditions at the site over a period of days. The contractor worked on moving the temporary 10 inch (25 cm) P.V.C. culvert utilized in diverting the running creek water in order to excavate material for construction of the west culvert headwalls. With the forming and reinforcement in place, the headwalls were poured and covered with insulated blankets. The county then backfilled the culvert with a mix of dry dirt and railroad gravel, compacting it with the aid of a bulldozer. The project was completed on November 21, 1990.

POST CONSTRUCTION OBSERVATIONS

After the balloon was removed, the interior of the arch could be observed. Two relatively large cracks had already appeared, one on each side of the arch approximately 7.0 feet (2.1 m) above the floor. These cracks ran nearly the length of the culvert. One reason may be that these cracks were the result of cold joints which formed while the first shotcrete sequence was allowed to set-up and harden. Another explanation could be that the shotcreting operation was done at more of an angle than should have been done, because the work platform could not extend properly from where it was located, and this inhibited the blow pipe operator from doing his job well. These defects should not damage the structural integrity of the arch. Since any load applied would result in compression of the concrete the horizontal cracks should close. These cracks were subsequently repaired with a non-shrinking grout.

CONCLUSIONS

In general, the project can be considered a success. The absence of a wall in the center of the structure, such as found in multiple box culverts, helps to eliminate obstructions and allows debris to flow through the structure. However, claims of this method being faster and less costly than normal box culvert construction techniques were not met. The contractor's bid of $51,763.00 was more than $10,000 over the cost estimate for a similar sized box culvert. One reason for the increased cost may simply be the research nature of the project, with this method performed only twice in Iowa and by different contractors. The primary reason may be that this method is best suited for construction of much longer and larger culvert barrels where the economics are more favorable. If the Air-O-Form method is to succeed at the county and state levels, it must become more cost competitive in Iowa's highly efficient culvert construction industry.

Appendix A

Contract

Form 740383 6/87

CONTRACT

Kind of Work Single Arch Air-O-Form Culvert Miles ------

Project No. LC-28-13N--73-24 County Crawford

THIS AGREEMENT made and entered by and between Crawford County, Iowa, by its Board of Supervisors consisting of the following members: Virgil E. Anderson, Don Jensen, LeRoy A. Hansohn, John P. Lawler, and Eileen Heiden, Contracting Authority, and Capital Constr. Co., Inc. P.O. Box 168 SE 8th Avenue of Logan, Iowa 51546, Contractor.

WITNESSETH: That the Contractor, for and in consideration of Fifty-one Thousand Seven Hundred Sixty-three & 00/100 Dollars ($ 51,763.00) payable as set forth in the specifications constituting a part of this contract, hereby agrees to construct in accordance with the plans and specifications therefore, and in the locations designated in the notice to bidders, the various items of work as follows:

Item No.	Item	Quantity	Unit Price	Amount
1.	Concrete, Structural Footing & Headwall	65.8 Cu.Yds	$ 180.00	$11,844.00
2.	Concrete, Structural, Arch	36.2 Cu.Yds	670.00	24,254.00
3.	Excavation, Class 10 Channel	300 Cu.Yds	3.00	900.00
4.	Excavation, Class 20	480 Cu.Yds	7.00	3,360.00
5.	Granular Material, Placement Only	71 Tons	3.00	213.00
6.	Mobilization	Lump Sum	2,000.00	2,000.00
7.	Piling, Steel Sheet	435 Sq.Ft.	10.00	4,350.00
8.	Steel, Reinforcing, Footing & Headwall	5,870 Lbs.	0.40	2,348.00
9.	Steel, Reinforcing, Arch	6,235 Lbs.	0.40	2,494.00
	TOTALS			$51,763.00

Said specifications and plans are hereby made a part of and the basis of this agreement, and a true copy of said plans and specifications are now on file in the office of the County Auditor under date of September 11, 19 90

That in consideration of the foregoing, the Contracting Authority hereby agrees to pay the Contractor, promptly and according to the requirements of the specifications the amounts set forth, subject to the conditions as set forth in the specifications.

That it is mutually understood and agreed by the parties hereto that the notice to bidders, the proposal, the specifications for Project No. LC-28-13N--73-24 in Crawford County, Iowa, the within contract, the contractor's bond, and the general and detailed plans are and constitute the basis of contract between the parties hereto.

That it is further understood and agreed by the parties of this contract that the above work shall be commenced and completed on or before:

Approximate Starting Date	Specified Starting Date	Specified Completion Date	Number of Working Days
		07-26-91	30

That time is the essence of this contract and that said contract contains all of the terms and conditions agreed upon by the parties hereto.

It is further understood that the Contractor consents to the jurisdiction of the courts of Iowa to hear, determine and render judgement as to any controversy arising hereunder.

IN WITNESS WHEREOF the parties hereto have set their hands for the purposes herein expressed to this and three other instruments of like tenor, as of the 2nd day of October 19 90

Approved:
IOWA DEPARTMENT OF TRANSPORTATION

By [signature] Contracts Engineer

Date OCT 11 1990

Crawford County, Io
Contracting Authority

By [signature]
Vice Chairman

Capital Construction Co., Inc.

By [signature]
Contractor

Appendix B

Material Sources

AGGREGATES

Type	Iowa DOT Prod. Spec.	Specific Gravity	Iowa DOT Source No.	Source Name
Motor Sand	4112-2	2.64	A-81504	Hosteng Conc. & Gravel, Auburn, IA
Concrete Sand	4110-1	2.67	A-81528	Carnarvon Sand & Gravel, Wall Lake/ Pittman
1/2" Gravel	4115 *	2.70	A-81502	Hallett Materials, Lake View

*Gradation used in pre-cast pipe production

CEMENT

Material	AASHTO Type	Specific Gravity	Producer
Fly Ash	C	2.55	Port Neal 4, Sioux City, IA
Portland Cement	I	3.14	Monarch Cement Co.

ADMIXTURES

Material	Brand	Producer
Air Entraining	Prokrete AES	Prokrete Ind. Lot No. 25359
Water Reducer	Prokrete N-3	Prokrete Ind. Lot No. 25360

Appendix C

Aggregate and Sand Gradations

*BLENDED SAND GRADATIONS (60% mortar sand, 40% concrete sand)

Sieve Size	Percent Passing Sieve: Mortar Sand	Concrete Sand	Calculated Blend Gradation	Blended Sample Gradation
3/8"	100	100	100	100
4	100	100	100	100
8	100	82	93	94
16	96	60	82	83
30	61	33	50	52
50	20	9.4	16	16
100	1.9	0.8	1.4	2.6
200	0.3	0.3	0.3	0.7

*Proportion by weight through ready mix plant. Mixed in a transit mixer and stockpiled as a blended sand.

COMBINED AGGREGATE GRADATION

Sample Identification / Sieve Size		1/2"	3/8"	4	8	16	30	50	100	200
		Percent Passing Sieve								
A.C.I. 506.2-77, Rev.83 Part 2,Table 2.2.1 #2	(min.) (max.)	90/ 100		70/ 85	50/ 70	35/ 55	20/ 35	8/ 20	2/ 10	
Contractor's gradation proposal		100	92	70	64	56	34	11	1.0	0.3
(1) Test mix sample proportioned sample		100	94	71	65	56	34	10	2.0	1.1
(2) Test mix, sample of shotcrete recovered aggregate		100	94	66	62	52	31	9.1	2.0	1.3
(3) Project acceptance proportioned sample		100	96	71	66	58	36	11	2.5	0.8
(4) Project assurance proportioned sample		100	95	71	66	58	36	12	2.1	0.7

1. Individual sand and gravel proportioning plant samples taken October 31, 1990 were mathematically combined using 70% blended sand and 30% 1/2" (1.3 cm) gravel.

2. Sample was secured from shotcrete applied to a test panel October 31, 1990. Cement and material passing the 200 mesh sieve was washed from the plastic shotcrete sample. The remaining aggregate was tested for gradation using standard I.M. procedures.

3. Proportioning plant mathematically combined sample test results. Sampled November 1, 1990 by Crawford County personnel.

4. Split sample verification of acceptance sample tests run by Iowa DOT Materials personnel. Mathematically combined results of blended sand and 1/2" (1.3 cm) gravel.

Appendix D

Mix Design

Material	Absolute Volume	Specific Gravity	Dry Batch Wt.(lb/cy)	(kg/m³)	Note
Blended Sand	0.44840	2.65 Avg.	2002	1190	(1)
1/2" (1.3 cm) Gravel	0.18932	2.69	858	509	
Cement	0.14215	3.14	752	446	
Fly Ash Type C	0.02328	2.55	100	59	(2)
Water	0.13685	1.000	230	136	(3)
Air Content	0.06000	---			
Water Reducer	---	---	3 oz/100 lb cement (89 ml/45 kg)		

(1) Blended sand: 60% mortar sand, Sp.Gr. 2.64 & 40% concrete sand, Sp.Gr. 2.67.
(2) Fly ash added to improve pumping.
(3) Water/cement plus fly ash ratio 0.27 lb/lb

Appendix E

Concrete/Shotcrete Testing

COMPRESSIVE STRENGTH

Shotcrete Test Cylinder Strength Results (6" dia. x 12"0) (15 cm x 30 cm)

Sample I.D.	Plastic (1)Air%	Conc. (2)Slump Inch	Date Made	Date Tested	Age (day)	Strength (PSI)	Strength (MPa)
Transit Mix discharge prior to pumping (Iowa DOT test)							
CB-1	5.9	2.0	11-1-90	11-29-90	28	6607	45.55
CB-2			11-1-90	11-29-90	28	597	4.12
CB-3			11-1-90	11-29-90	28	5719	39.43
Avg.						.6101	42.06
Shotcrete applied to vertical panel (Iowa DOT test)							
CB-4	4.4(3)	1.0(3)	11-1-90	11-29-90	28	6384	44.02
CB-5			11-1-90	11-29-90	28	6126	42.24
CB-6			11-1-90	11-29-90	28	6051	41.72
Avg.						.6187	42.66
Transit mix discharge prior to pumping (contractor test results)							
3A			11-1-90	11-2-90	1	2510	17.31
3B			11-1-90	11-8-90	7	5230	36.06
3C			11-1-90	11-15-90	14	5660	39.02
3D			11-1-90	11-29-90	28	6300	43.44

(1) Loss of air content due to shotcrete application 1.5%
(2) Loss of slump due to shotcrete application 1.0 inch (2.5 cm)
(3) Sample removed from applied shotcrete and tested according to Iowa DOT Standard I.M.'s.

FLEXURAL STRENGTH

Flexural Beam Strength Results

Material Sample Location	Sample I.D.	Plastic Air%	Conc. Slump Inch	Date Made	Date Tested	Age (day)	Strength (PSI)	Strength (kPa)
Transit mixer discharge prior to pumping (Iowa DOT test)	BT-1	5.9	2.0	11-1-90	11-3-90	2	558	3850
	BT-2	5.9	2.0	11-1-90	11-8-90	7	782	5390
*Shotcrete applied to vertical panel (Iowa DOT test)	BM-1	4.4	1.0	11-1-90	11-3-90	2	558	3850
	BM-2	4.4	1.0	11-1-90	11-8-90	7	719	4960

*Material for flexural beams was obtained from shotcrete applied concrete. Beams were made and tested according to Iowa DOT I.M. test procedures.

CORE COMPRESSIVE STRENGTH
SHOTCRETE CORE TEST STRENGTH RESULT

Material Sample Location	I.D. or Lab No.	Plastic Air %	Conc. Slump Inch	Hardened Conc. Air %	Date Placed	Date Tested	Age (Day)	Strength (PSI)	Strength (MPa)
Cores from vertical shotcrete panel (Iowa DOT test)	35-11-1	4.4	1.0	4.3	11-1-90	11-29-90	28	7350	50.68
	35-11-2				11-1-90	11-29-90	28	6640	45.78
	35-11-3				11-1-90	11-29-90	28	7180	49.50
	Avg.							7057	48.66
Contractor secured core from concrete arch culvert	#1				11-1-90	11-29-90	28	4030*	27.79

*Steel reinforcing bar in core -- test result is invalid.

Photo 1: Metal band installation prior to balloon inflation

Photo 2: Reinforcing steel placement on inflated balloon

Appendix F

Construction Photos

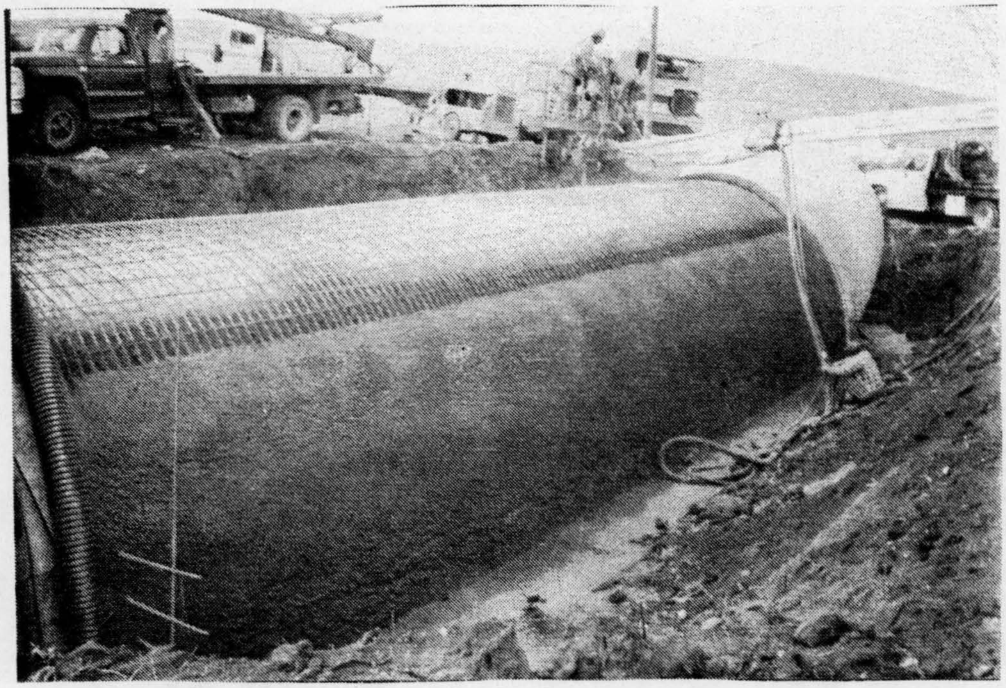

Photo 3: First stage of shotcreting operation

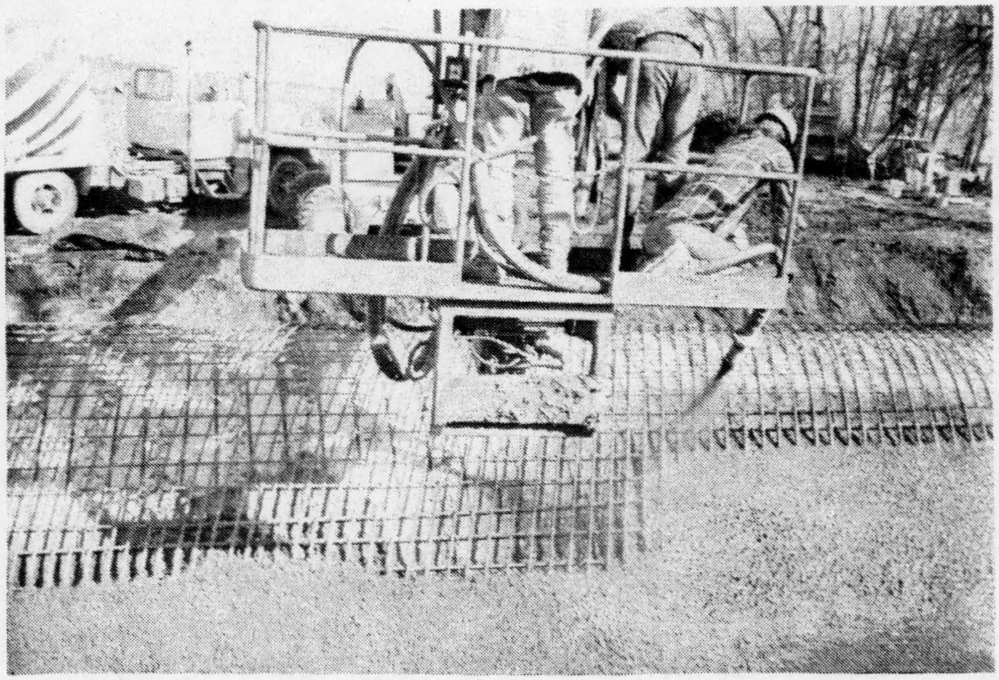

Photo 4: Completing shotcreting operation

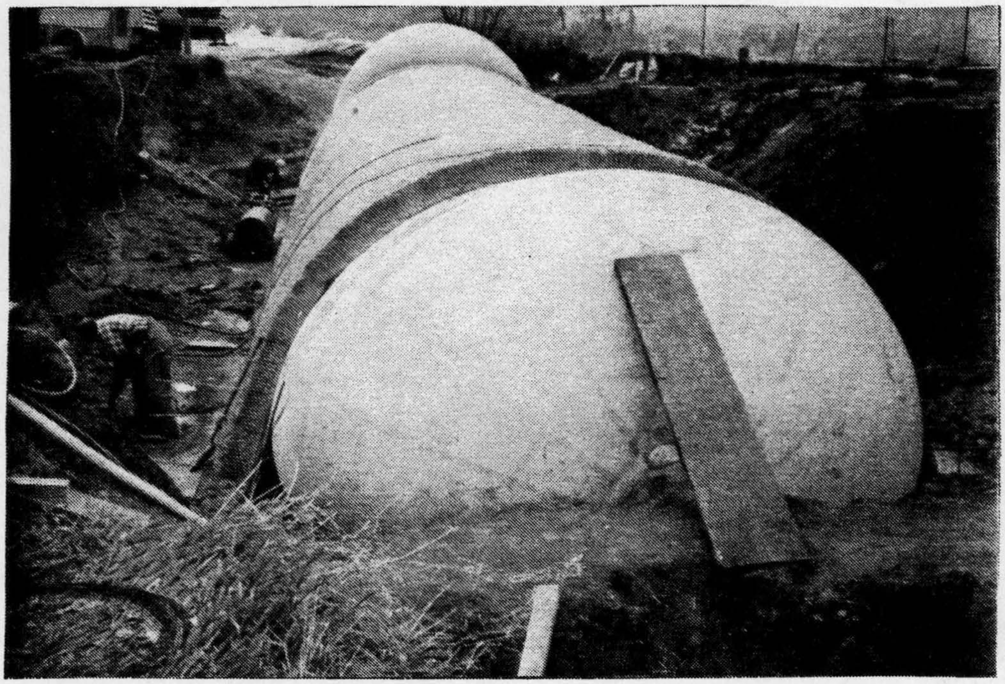

Photo 5: Concrete arch culvert in place

Photo 6: Finished arch culvert with backfill